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RECENT DEVELOPMENTS IN THERMOPHILIC SLUDGE DIGESTION IN THE UNITED STATES

by

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16. ABSTRACT

Anaerobic digestion is one of the most widely used processes for sludge stabilization. The paper reviews the developments of thermophilic sludge digestion including the successsful demonstrations at Los Angeles and Chicago. Two recent developments, Multiple Digestion Process as advanced by Torpey in New York and dual digestion system as demonstrated in Hagerstown, Maryland and in Lackawanna, New York are reviewed in detail. It is concluded that the thermophilic digestion process, aerobic, anaerobic or in combination with mesophilic digestion process has been shown to be equivalent or better compared with conventional sludge stabilization processes when operated under research conditions. A brief description of the planned work at the U.S. EPA Test and Evaluation Facility, Cincinnati, Ohio, for further evaluations is given.

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INTRODUCTION

Anaerobic digestion is one of the most widely used processes for sludge stabilization. The principal purposes of stabilization are to make the treated sludge less odorous and putrescible and to reduce the pathogenic organism content. Anaerobic as well as aerobic digestion are currently increasing in popularity. The former is receiving revived attention from some cities and new attention from others for several reasons. The production of methane in anaerobic digestion is attractive in view of energy shortages, as is the suitability of anaerobically digested sludges to disposal on land. Also, it is being recognized that problems experienced previously with anaerobic digestion were actually due to other wastewater process considerations. Interest in aerobic digestion of excess activated sludge is growing because it has the potential for providing a good quality liquid process stream and can produce exothermic reaction conditions. A major impetus for processes such as anaerobic and aerobic digestion is the growing emphasis on utilization of sludge rather than mere disposal. Wastewater sludges have been applied to land as fertilizer and as soil conditioner for many years. To protect the public health, federal regulations have been promulgated to govern land application of sludge. In defining an acceptable degree of sludge treatment, the USEPA developed two classifications of processes, Processes to Significantly Reduce Pathogens (PSRP) and Processes to Further Reduce Pathogens (PFRP)(1). Treatment by a PSRP will produce a sludge acceptable for land application provided that public access is controlled for at least 12 months, grazing by animals whose products are consumed by humans is prevented for at least one month, and food crops for direct human consumption (in which the sludge contacts the edible part of the plant) are not grown within 18 months. Sludge applied to land used for growing crops within 18 months in which the edible part of the plant is contacted needs to be treated by a PFRP. The other two restrictions on access and grazing also apply to PFRP treated sludge. PSRPs and PFRPs are defined in terms of operation of a number of processes operated under specified conditions (e.g., anaerobic digestion for 15 days at 35°C to 50°C with a volatile solids reduction of at least 38% is a PSRP). In this classification aerobic digestion and anaerobic digestion are considered PSRP, but thermophilic aerobic digestion is considered PFRP. The description of these processes as well as others are given in Appendices 1 and 2.

Operation of digestors (50°C - 60°C) in the thermophilic region has been periodically tested at bench- and pilot-scale for 50 years. During the last 30 years several full-scale thermophilic digestion systems have been placed in operation including ones in Moscow, U.S.S.R (2). In general, the thermophilic systems, bench, pilot and field, operated successfully. However, operation of most of these full-scale thermophilic systems has been terminated. At the present time only one digester at the City of Los Angeles' Hyperion plant is being operated in this mode.

An extensive literature review of experiences with thermophilic digestion was recently published by Buhr and Andrews (3). They summarized virtually all of the significant research work and field experience prior to the late 1970's. The major findings of their study are presented below.

Buhr and Andrews reported that: a) At thermophilic conditions, the rate of destruction of organic solids is greater than at mesophilic temperatures. Shorter residence times can thus be used; b) Some studies indicated superior dewatering of thermophilic sludges while others indicated poorer dewatering. Supernatant quality was poorer for thermophilic sludges; c) Far better destruction of pathogens could be expected in thermophilic systems compared to mesophilic systems at equivalent detention time; d) The effect of temperature fluctuations on digester performance was not clear for either mesophilic or thermophilic conditions. Significant lowering of temperatures for short periods resulted in a cessation of biological activity but without permanent effect.

Recently Garber (4) and Rimkus et al. (5) reported on relatively long term successful operation of full-scale thermophilic digestion in parallel with mesophilic digestion. Garber reported superior dewatering of thermophilic sludges in centrifuges and superior pathogen inactivation. Solids destruction was the same with both systems operating at 20-day detention (a relatively long detention time). However, in an earlier study at the same site, Garber reported better COD and grease removals in thermophilic systems (6). Chicago experiments were carried out on a 8900 m^3 digester (33.5 m diam. x 11 m) with an identical digester used as a mesophilic control (5). When operated at 14 days residence time, gas production per unit mass of volatile solids (VS) fed was higher (0.40 m^3/kg fed versus 0.32 m^3/kg) for the thermophilic digester (52°C) than for the mesophilic digester (35°C). However, the mesophilic digester produced more surplus gas (0.18 m^3/kg fed versus 0.09 m^3/kg) because its heating needs were lower. When the thermophilic digester was reduced to 7 days residence time and the mesophilic digester was kept at 14 days, the thermophilic digester continued to show superior performance.

Despite the evident superior performance of thermophilic digestion, Chicago has recently proceeded with plans to greatly expand its mesophilic digestion capabity. The primary reason for this choice was uncertainty about the odor of the thermophilically digested sludge. Odor was definitely different from mesophilically digested sludge, and was shown to be slightly more intense. Since Chicago's sludge is temporarily stored in lagoons near heavily traveled highways, it was thought prudent to remain safe since there was insufficient time to devise and carry out tests for acceptability before a decision had to be made.

Currently, a cooperative study between the U.S. EPA and Dr. Irwin Kugelman at Lehigh University is being conducted for a comparative study of mesophilic and thermophilic digestions. In this study 1-liter digesters are being operated at 35°C and 55°C at detention times varying from 15 days to 5 days. They will be monitored for parameters to evaluate degree of stabilization, sludge dewaterability, sludge odor, and stability under loading stress. The results of this work are not available at this time.

MULTIPLE DIGESTION PROCESS

A recent innovative approach to digestion was demonstrated on a large scale by W. Torpey at New York City's Rockaway Sewage Treatment Plant. This work has been described in a recent presentation (7). The process

flow scheme used at Rockaway is presented in Figure 1. Raw and waste activated sludge are thickened (T-1), digested mesophilically (35°C) in Digester D-1, and digested thermophilically (49°C) in Digester D-2. The flow is then divided approximately in half. One half goes to the aerator; the other half is simultaneously elutriated and thickened (T-2) and withdrawn as product. Overflow streams from Thickeners T-1 and T-2 are returned to the primary influent.

Torpey et al, (7) reported results obtained during a four month operating period. Residence time in each digester during these tests has been been 13 days. Reduction in sludge volatile solids of 82 percent was achieved as compared to 56 percent reduction obtained in an equivalent period using conventional mesophilic conditions. Sludge volume discharged was reduced by an equivalent amount. The authors state that effluent quality did not deteriorate during the operating period. No data were obtained on change in oxygen requirement in the activated sludge process.

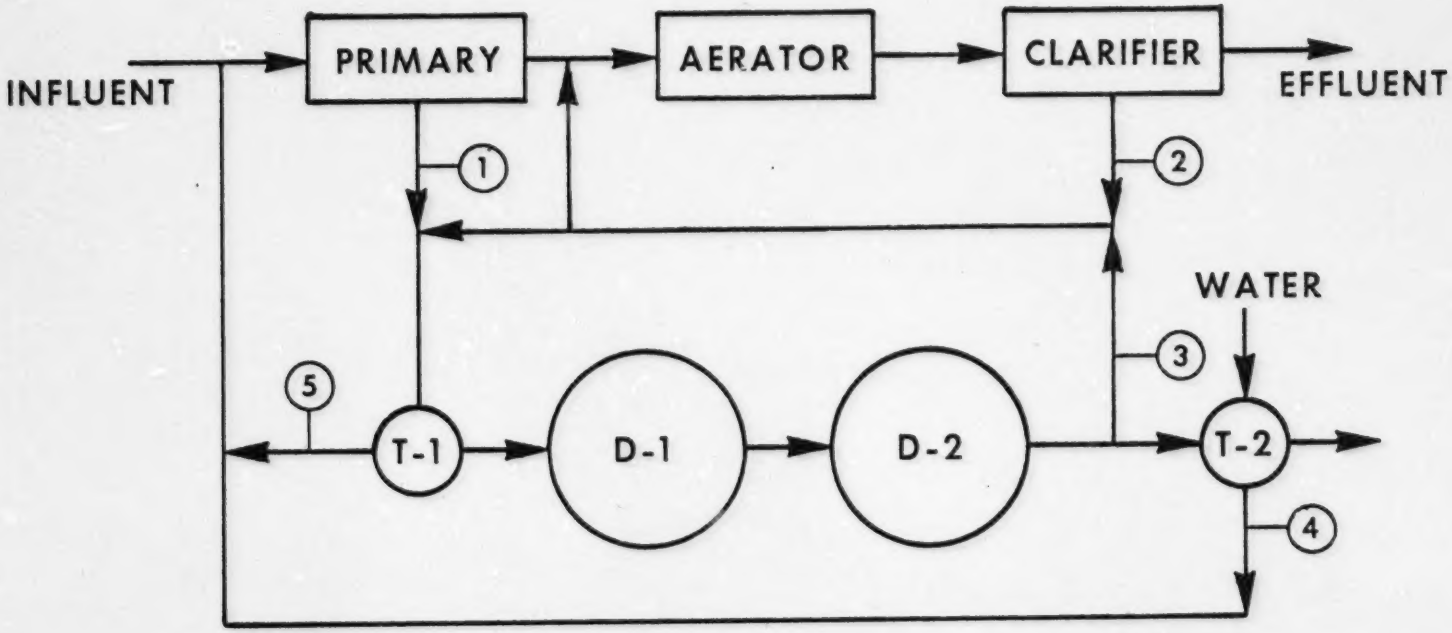
The Rockaway plant is still operating in the multiple digestion mode, although recirculation to the aerator has been discontinued pending installation of larger diameter piping. The new treatment plants under construction or in design at New York City (North River, Red Hook, Coney Island, and Owls Head) will be equipped to run in Torpey's multiple digestion mode. Operation, however, may not actually start until 1990.

The North River plant is designed for a sewage flow of 0.644×10^6 m^3/da. Design sludge flow for the mesophilic digester is 1,136 m^3/da of 6.3% solids sludge. Residence time in each digester is 20.8 days. There will be four mesophilic and four thermophilic digesters of equal size. Operation is similar to the flow scheme shown in Figure 1 except return activated sludge and return digested sludge go directly to the aeration tanks--waste activated sludge is split off from the return sludge before return digested sludge mixes with return activated sludge.

DUAL DIGESTION SYSTEM (DDS)

Dual Digestion System (DDS) was developed by Union Carbide Corporation in the 1970s and is currently marketed by Lotepro Corporation (New York, NY). Details of the development are presented in Drnevich and Matsch (8) and Castillo, et al. (9). Bench- and pilot-scale testing of DDS indicated solids destruction comparable to conventional biological processes. The first full-scale dual digestion system was operated at Hagerstown, Maryland (10).

The Hagerstown Wastewater Treatment Plant consists of a short retention time, autothermal, aerobic digester followed in series by an existing anaerobic digestion step. The primary purpose of this process is to stabilize and pasteurize the thickened waste secondary sludge produced by the air-activated sludge plant through the reduction of volatile matter in the sludge and the production of methane in the second step. The pasteurized residue can then be trucked for safe disposal on land. Figure 2 presents a process flow schematic for the dual digestion system.



T-1 THICKENER
D-1 DIGESTER (35°C)
D-2 DIGESTER (49°C)
T-2 THICKENER

1. PRIMARY SLUDGE
2. RETURN ACTIVATED SLUDGE
3. RECIRCULATED DIGESTED SLUDGE
4. ELUTRIATE
5. THICKENER OVERFLOW

Figure 1. Multiple Digestion Experiment at Rockaway, N.Y.

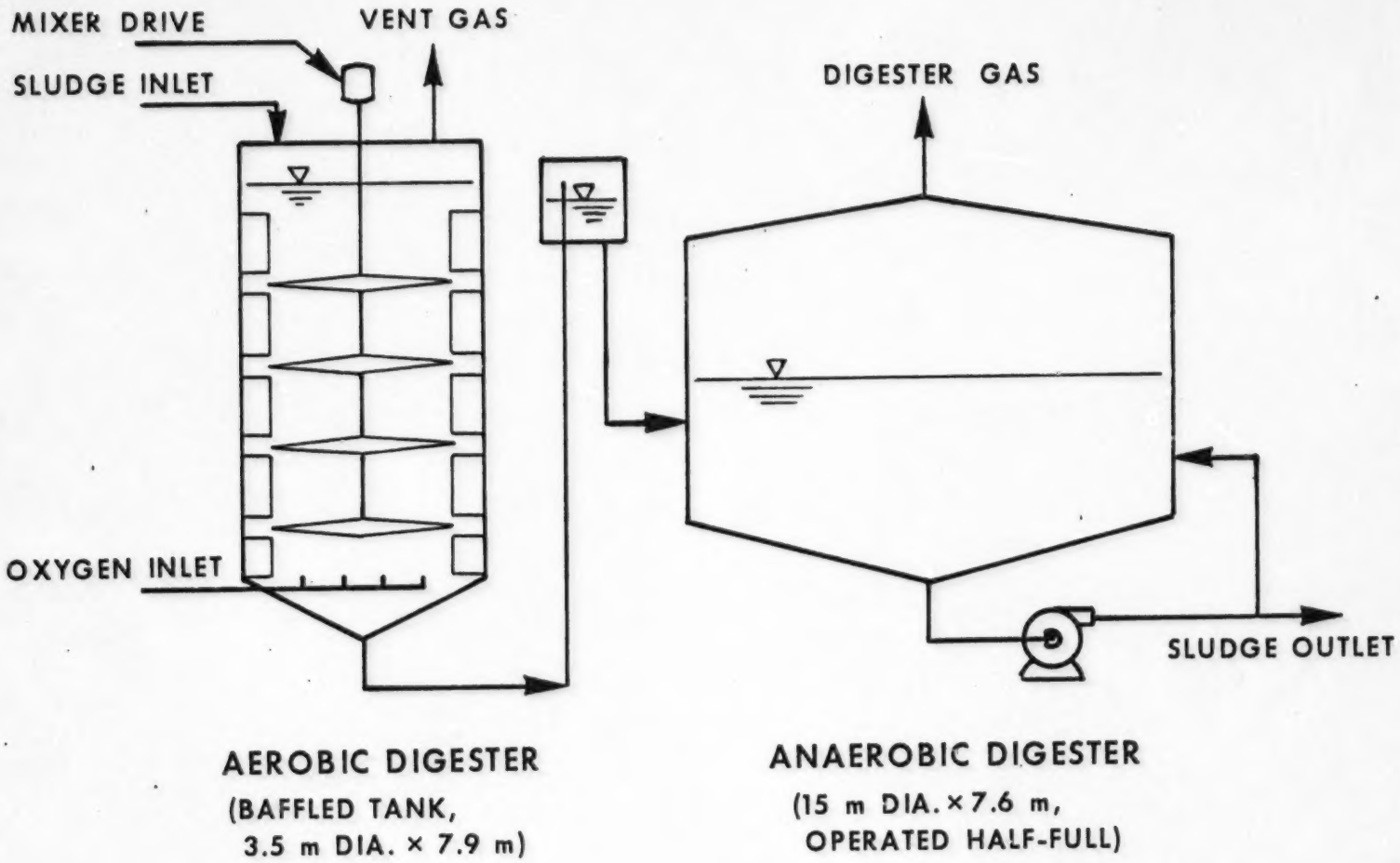


Figure 2. Dual Digestion System at Hagerstown, Maryland

The first step of the dual digestion system consists of a high-rate autothermal aerobic digester contained in an insulated, covered, concrete tank of cylindrical geometry. The tank is 3.5 m in inside diameter with a maximum sludge sidewater depth of 7.3 m and a minimum freeboard height of 0.6 m. An adjustable external telescoping valve and overflow box maintains the liquid height in the aerobic digester at a depth of between 6.1 and 7.3 m. During its demonstration program, the liquid level was maintained at 20 feet, creating a reactor volume of 62 m^3 which includes the volume of the drainage well at the bottom of the tank. The aerobic reactor can be maintained at thermophilic temperatures (greater than 45°C) through the conservation of heat generated by biological oxidation of degradable organic matter in the waste sludge and does not require the use of an external heat source. High purity oxygen is introduced into the aerobic reactor by means of static course bubble diffusers located at the bottom of the tank. Oxygen transfer from the gas to the liquid phase is enhanced by means of a rotating high-shear device that breaks up the oxygen gas bubbles as they rise through the sludge. The use of high-purity oxygen, in addition to enhancing the oxygen transfer rate, minimizes the volume of water saturated gas (mainly carbon dioxide and oxygen) vented to the atmosphere. This low gas volume minimizes latent and sensible heat losses from the aerobic step and allows the desired operating temperature to be maintained more efficiently. The major mode of temperature control in the first step is the adjustment of the oxygen feed rate and thus the extent of heat-producing biological oxidation that occurs. Typically, only 5 to 15 percent of the volatile solids content of the sludge needs to be metabolized to produce the required quantity of heat, depending on the desired operating temperature, environmental heat losses, and influent sludge characteristics. The latter was a crucial factor during the Hagerstown program because of persistently low feed solids concentration (<4%TS). This factor necessitated the occasional use of sludge flow adjustment as another mode of temperature control when feed solids concentrations dropped below critical levels. By decreasing the sludge flow rate, the amount of heat lost with the aerobic sludge effluent was reduced. Despite the undesirability and inconvenience of low sludge concentrations, the ability to control the process was effectively demonstrated.

The second step of the dual digestion system consists of a high-rate anaerobic digester that receives the heated and partially digested sludge from the autothermal aerobic pretreatment step. The anaerobic reactor completes the stabilization process by further breaking down volatile matter into carbon dioxide and methane gas. For purposes of this investigation, an existing fixed-cover anaerobic digester with a single 15.2 m diameter tank and a sidewater depth of 7.6 m (nominal capacity of 1500 m^3) was used. To keep anaerobic hydraulic retention times within a reasonable range and yet maintain a gas seal over the mid-depth influent sludge pipe, the reactor was operated at slightly more than half of its total volume. The reactor cover was sealed to prevent gas leakage at this reduced liquid level. A 5600 W pump was installed for sludge wasting and recirculation mixing.

Process Observations

The Hagerstown dual digestion demonstration plant was started on June 11, 1980, with the aerobic reactor being filled to the 6.1 m level

(approximately 62 m^3) with thickened secondary sludge. Beginning June 13, a secondary sludge feed was initiated at a rate sufficient to maintain a 1-day aerobic retention time. By the end of the seventh day of operation, the aerobic digester temperature had risen to the thermophilic region (greater than 45°C). By the ninth day the temperature had reached 55°C without the aid of external heating. At that point, the oxygen feed rate was lowered to stabilize the sludge temperature and increase oxygen utilization.

Thermophilic temperatures were maintained in the aerobic step despite a wide range of process and operating conditions. Table 1 summarizes phase average values of key parameters for the 20 weeks of continuous operation documented in this report. In addition to the data listed, information was also obtained concerning heat and oxygen balances around the aerobic reactor, kinetic rate constants, high-shear power draw, pasteurization performance (bacteria, viruses, and parasites), and process stability and flexibility.

The Hagerstown Results

The Hagerstown dual digestion system has successfully demonstrated that thermophilic temperatures may be autothermally achieved and maintained in a full-scale system at relatively short (0.95 to 2.25 days) aerobic retention times. Despite wide variations in sludge feed flow rates, solids concentrations, and degradability, control of aerobic reactor temperature was maintained through simple adjustment of the oxygen feed flow rates and hydraulic retention times.

Volatile solids removal rates averaged 27.2 percent across the aerobic step and 41.6 percent over the entire system. These values agree well with historical, mesophilic, anaerobic digester performance at much longer (20 to 50 days) retention time. Oxygen consumption ratios in the range of 1.6 to 1.8 kg oxygen per kg of volatile solids removed were found by mass balances around the aerobic step. The aerobic heat of reaction was found to be a function of the extent of volatile solids removal and varied in the 7000 to 22000 kj/kg of volatile solids removed. These values are consistent with expected results for operation on waste secondary air-activated sludge at relatively low influent solids concentrations (1.9 to 2.9 percent volatile solids). The results confirm design model predictions and allow extrapolations to higher solids concentrations with confidence.

The high-shear aeration device successfully demonstrated sufficient oxygen transfer capacity to achieve and maintain thermophilic temperatures in the aerobic step at short hydraulic retention times and reasonable power densities (100 to 220 W/m^3). The capability of the device for efficient oxygenation of thickened, waste-activated sludge was also proved. Oxygen use exceeded 65 percent of the feed gas flow when the shear device was operated at 32.2 rpm. Furthermore, the data suggested that the efficiency of the high-shear device would be enhanced at higher influent sludge concentrations. Solids and temperature profiles indicated that the contents of the aerobic reactor were reasonably well mixed under all conditions.

TABLE 1. Test Program Process Conditions

Parameter	Phase Average	Range
Aerobic retention time, days	1.38	0.6 - 8.8
Anaerobic retention time, days	19.9	9.6 - 34.0
Temperature, °C		
Feed	23.8	16.8 - 28.3
Aerobic	50.5	42.3 - 60.0
Anaerobic	41.7	37.5 - 47.0
Ambient	21.5	5.0 - 40.0
Solids concentration, %		
TS	3.02	1.50 - 4.11
VS	2.41	1.23 - 3.33
Volatile solids removal, %		
Aerobic	27.2	15 - 51
Overall	41.6	24 - 57
Oxygen flow rate, CFM NTP	19.2	10.3 - 33.4
Gas purities, %		
Aerobic vent O_2	68.9	31.5 - 91.5
Anaerobic vent CH_4	49.1	35.5 - 62.5
CO_2	33.1	24.2 - 49.5
O_2	1.6	0 - 4.5
pH		
Feed	6.00	5.5 - 6.9
Aerobic	7.09	6.6 - 7.7
Anaerobic	7.30	6.7 - 7.65

Preliminary information obtained from an aerobic digester temporarily used as the second process step indicates that good overall volatile solids destruction, process stability, and acceptable methane purities are possible with the dual digestion system. Total alkalinity and volatile acid concentrations for the anaerobic step averaged 3559 and 265 mg/L, respectively, during the course of the test program.

Data collected on bacteria, virus, and parasite kills demonstrate the ability of the dual digestion system to reduce significantly (by several orders of magnitude) the levels of human pathogens when operated at thermophilic temperatures (Table 2).

Lackawanna Wastewater Treatment Plant

In addition to the Hagerstown plant, to date DDS has been installed at two other treatment plants in the U.S.: Nutbush Creek WWTP (Henderson, NC), and Lackawanna WWTP (Lackawanna, NY). All three plants include the UNOX process in their secondary treatment scheme, so the costs for pure oxygen for DDS were expansion increments to the base cost of a pressure swing adsorption (PSA) oxygen generation system sized to meet UNOX demands. This resulted in a higher calculated cost savings of DDS than had DDS been the only process requiring pure oxygen. All three plants are also similar in that they formerly used conventional two-stage anaerobic digestion. A new reactor was constructed to serve as the Step I digester, and the former first-stage digester serves as the Step II digester. The former second stage digester provided some additional solids stabilization and some solid/solution separation through gravity thickening. Recently Lackawanna WWTP DDS has been evaluated by James M. Montgomery Consulting Engineers, Inc. The final report of this evaluation is in preparatin (11). The following is a summary of their findings.

Figure 3 is a schematic of the DDS system at the Lackawanna WWTP. Sludge is continuously fed to the Step I digester from the gravity thickener. The level of sludge in the Step I digester can be controlled to some degree by a telescoping valve. High levels of oxygen transfer are achieved in Step I by the mass transfer device which slowly rotates, shearing the rising oxygen bubbles to provide a higher interfacial surface area. To provide a Step II design detention time of approximately 8 days, a smaller diameter reactor was constructed within the old digesters. Biogas produced through anaerobic digestion can be used to fuel a gas engine to drive the PSA compressor or to provide space heating requirements.

Microbiological sampling at the Lackawanna WWTP was conducted in three separate phases of approximately ten weeks each between July 1984 and April 1985. The sampling program was designed to obtain thirty samples for adequate characterization of the degree of microbial inactivation provided by DDS.

Preliminary Lackawanna Results

The results of the microbioligical analyses and the total solids analyses were used to calculate microbial densities in units of most probable number (MPN) per gram of dry sludge (Table 3).

Table 2. Summary of Pasteurization Results at Hagerstown
(Average values for the indicated periods)

Indicator	Dual Digestion System (06-16-80)-(10-27-80)			Control Digester (03-31-80)-(04-14-80)	
	Raw Sludge	Aerobic Effluent	Anaerobic Effluent	Feed	Effluent
Fecal Coliform $\frac{\text{MPN}}{100\ \text{ml}}$	6.6×10^{7}	4.3×10^{5}	9.5×10^{4}	2.5×10^{7}	4.4×10^{6}
Total Coliform $\frac{\text{MPN}}{100\ \text{ml}}$	4×10^{9}	6.4×10^{6}	1.1×10^{5}	4.6×10^{8}	5.1×10^{7}
Fecal Streptocci $\frac{\text{Bacteria}}{100\ \text{ml}}$	1.2×10^{7}	4.1×10^{5}	4.9×10^{5}	8.5×10^{6}	7.5×10^{5}
Salmonella Sp $\frac{\text{MPN}}{100\ \text{ml}}$	205	BDL*	109	35.5	21.7
Virus $\frac{\text{PFU}}{100\ \text{ml}}$	784	<2.0	<2.5	197.5	26

*BDL - Below detectable limit

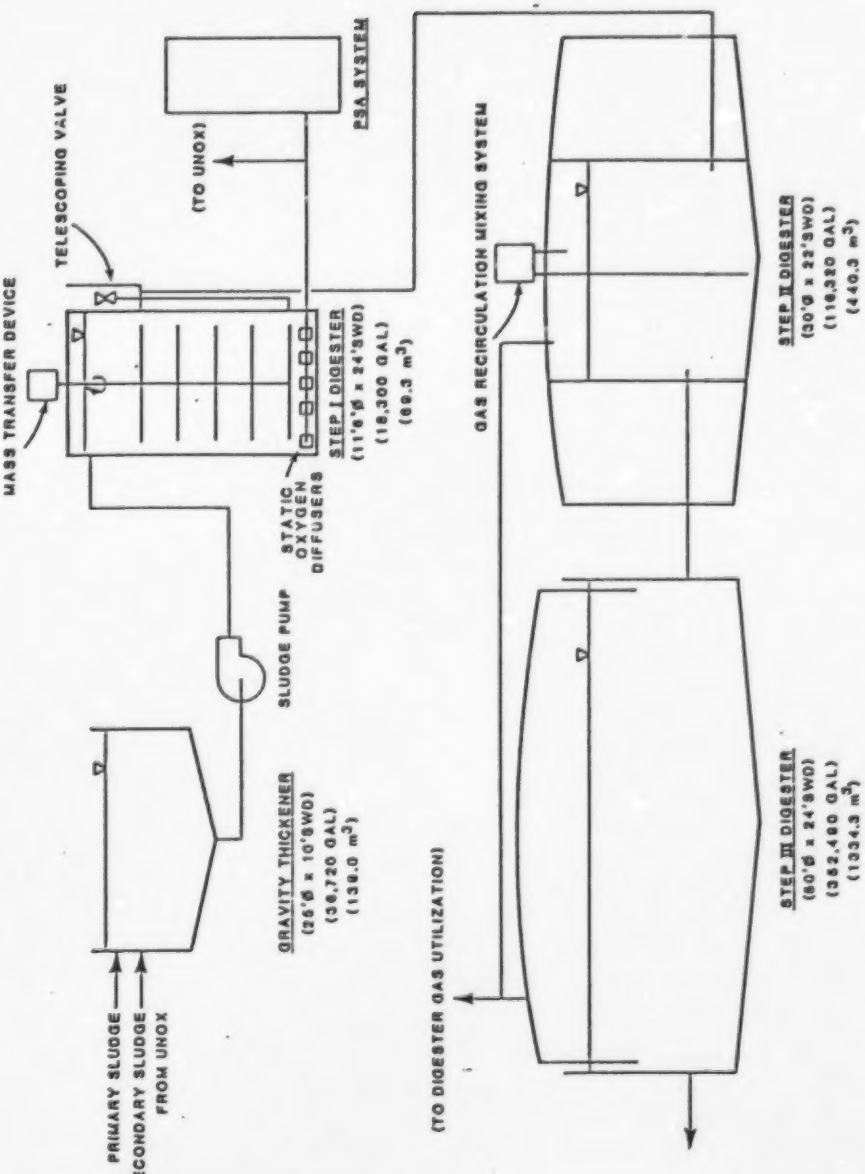


Figure 3. Dual Digestion System at Lackawanna, N.Y.

TABLE 3. Microbiological Sampling Results

	Phase IA Geometric Mean[a]	Phase IB Geometric Mean[a]	Phase II Geometric Mean[a]	Phase III Geometric Mean[a]
Total Coliform				
Step I Influent	1.22×10^6	1.46×10^6	1.31×10^8	7.17×10^7
Step I Effluent	7.42×10^2	2.26×10^3	7.28×10^3	4.92×10^4
Step II Effluent	1.53×10^2	1.62×10^3	3.70×10^2	3.71×10^4
Fecal Coliform				
Step I Influent	2.86×10^5	2.30×10^5	2.25×10^7	1.54×10^7
Step I Effluent	5.01×10^2	6.01×10^3	3.78×10^3	3.28×10^4
Step II Effluent	1.04×10^2	1.13×10^3	1.96×10^2	2.11×10^4
Fecal Streptococci				
Step I Influent	NA	NA	6.69×10^6	4.46×10^6
Step I Effluent	NA	NA	4.90×10^4	2.43×10^5
Step II Effluent	NA	NA	6.56×10^3	5.79×10^4
Salmonella spp.				
Step I Influent	NA	NA	1.33×10^1	4.95
Step I Effluent	NA	NA	1.68	8.03
Step II Effluent	NA	NA	1.14	9.74

NA = not analyzed
[a] = concentration in MPN/g dry sludge

In Table 4 the calculated mean log reductions are presented. The effectiveness of DDS in achieving pathogen destruction in comparison to processes classified as PSRP or PFRP was evaluated. Comparing the performance of DDS during peak operation in Phase II to that of thermophilic aerobic digestion, a PFRP, greater reductions of total coliform and fecal coliform were observed for DDS. Fecal streptococci reductions were nearly equal for the two processes. It is difficult to accurately compare the reductions in Salmonella spp. because of their low concentrations relative to their analytical detection limit of 2 MPN/100 ml.

In summary, operation of DDS at the Lackawanna WWTP demonstrated that adequate total volatile solids reduction could be achieved relative to PSRP and PFRP. Reductions of the three indicator microbiological parameters of interest through DDS treatment were greater than those achieved by PSRPs and greater than or equal to those achieved by thermophilic aerobic digestion, a PFRP. Salmonella spp. data were difficult to compare, but it appears that greater reductions of this pathogenic bacteria can be achieved with PSRPs. Regrowth of Salmonella spp. in the Step II digester was not observed during this study.

SUMMARY AND FUTURE U.S. EPA RESEARCH

The thermophilic digestion process, aerobic, anaerobic or in combination with mesophilic digestion process is shown to be equivalent or better compared with conventional sludge stabilization processes when operated under research conditions. However, there are still several economic and operational questions which need to be answered before these innovative digestion schemes reviewed in this paper are adopted by many treatment plants. One area of concern is that most of the compared processes have been operated in different locations with different sludges, and with different operating personnel. Comparisons cannot always be made with confidence. In order to eliminate extraneous process variables an experimental program was initiated at the U.S. EPA Test and Evaluation Facility in Cincinnati, Ohio. A pilot plant consisting of two 0.19 m^3, two 1.7 m^3 and two 3.8 m^3 digesters were constructed. The system is flexible enough to allow these digester tanks to be used in any combination. The construction is nearly complete and experiments are expected to start in October 1985. The alternatives to be studied in the first step of this program are a) mesophilic digestion to be used as a control, b) thermophilic digestion, c) two-stage autothermal aerobic/anaerobic digestion, and d) two-phase anaerobic digestion. The process flow diagram of these systems is shown in Figure 4. It is expected that the results of this research will provide engineers much needed data to compare and judge the many alternative sludge digestion processes.

Table 4. Mean Log Reductions

	Total Coliform	Fecal Coliform	Fecal Streptococci	Salmonella spp.
Phase IA				
Influent - Step I	3.2	2.8		
Step I - Step II	0.7	0.7		
Overall	3.9	3.4		
Phase IB				
Influent - Step I	2.8	1.6		
Step I - Step II	0.1	0.7		
Overall	2.9	2.3		
Phase II				
Influent - Step I	4.3	3.8	2.1	0.9
Step I - Step II	1.3	1.3	0.9	0.2
Overall	5.5	5.1	3.0	1.1
Phase III				
Influent - Step I	3.2	2.7	1.3	-0.2
Step I - Step II	0.1	0.2	0.6	-0.1
Overall	3.3	2.9	1.9	-0.3

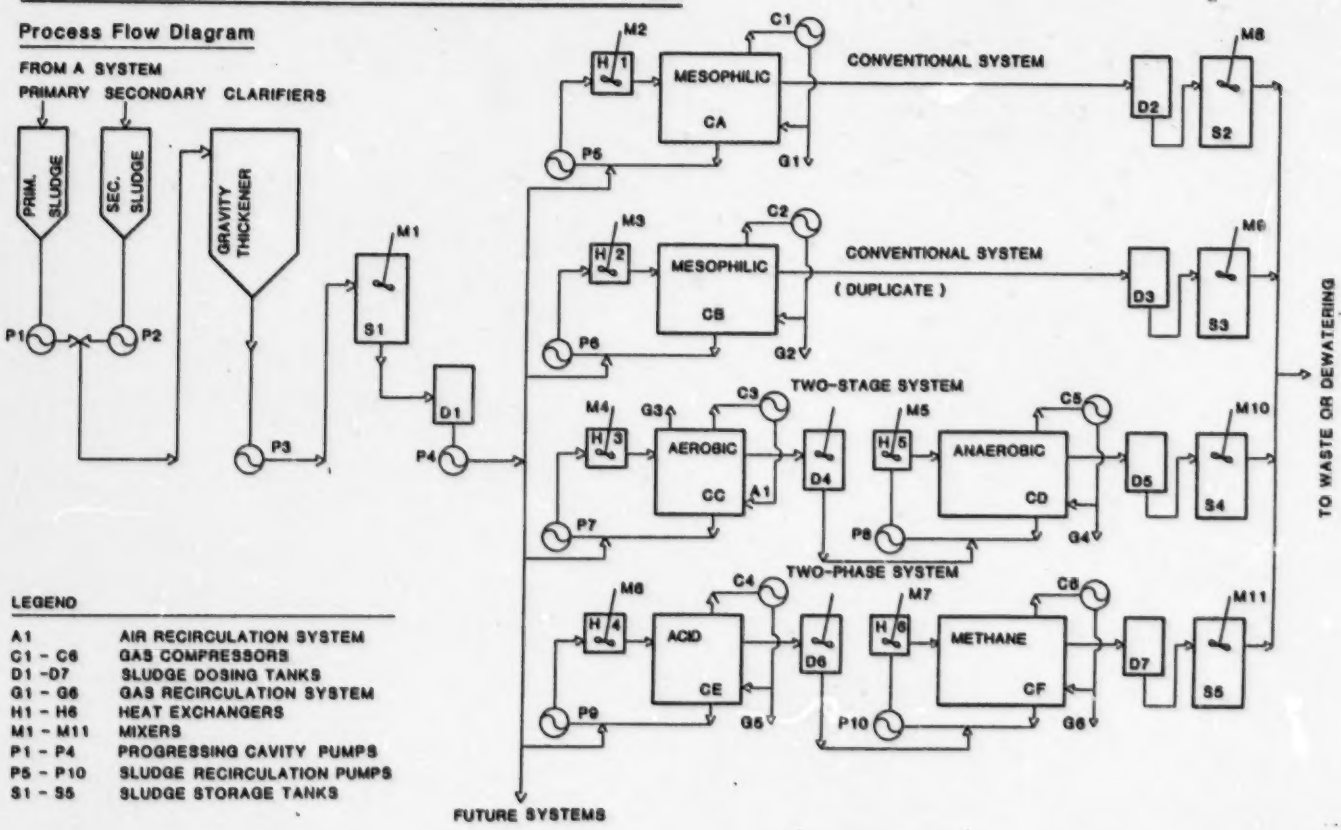


Figure 4. Flow Diagram of Test and Evaluation Digestion Research

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APPENDIX 1

PROCESSES TO SIGNIFICANTLY REDUCE PATHOGENS (PSRP)

Aerobic Digestion: The process is conducted by agitating sludge with air or oxygen to maintain aerobic conditions at residence times ranging from 60 days at 15°C to 40 days at 20°C, with a volatile solids reduction of at least 38%.

Air Drying: Liquid sludge is allowed to drain and/or dry on under-drained sand beds or paved or unpaved basins in which the sludge is at a depth of 23 cm. A minimum of three months is needed, during two months of which daily temperature averages above 0°C.

Anaerobic Digestion: The process is conducted in the absence of air at residence times ranging from 60 days at 20°C to 15 days at 35° to 55°C, with a volatile solids reduction of at least 38%.

Composting: Using the within-vessel, static aerated pile, or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40°C for five days. For four hours during this period, the temperature exceeds 55°C.

Lime Stabilization: Sufficient lime is added to produce a pH of 12 after two hours of contact.

Other Methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

APPENDIX 2

PROCESSES TO FURTHER REDUCE PATHOGENS (PFRP)

Composting: Using the within-vessel composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days. Using the static aerated pile composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days. Using the windrow composting method, the solid waste attains a temperature of 55°C or greater for at least 15 days during the composting period. During the high temperature period, there also will be a minimum of five turnings of the windrow.

Heat Drying: Dewatered sludge cake is dried by direct or indirect contact with hot gases, and moisture content is reduced to 10% or lower. Sludge particles reach temperatures well in excess of 80°C, or the wet bulb temperature of the gas stream in contact with the sludge at the point where it leaves the dryer is in excess of 80°C.

Heat Treatment: Liquid sludge is heated to temperatures of 180°C for 30 minutes.

Thermophilic Aerobic Digestion: Liquid sludge is agitated with air or oxygen to maintain aerobic conditions at residence times of 10 days at 55°C to 60°C, with a volatile solids reduction of at least 38%.

Other Methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.